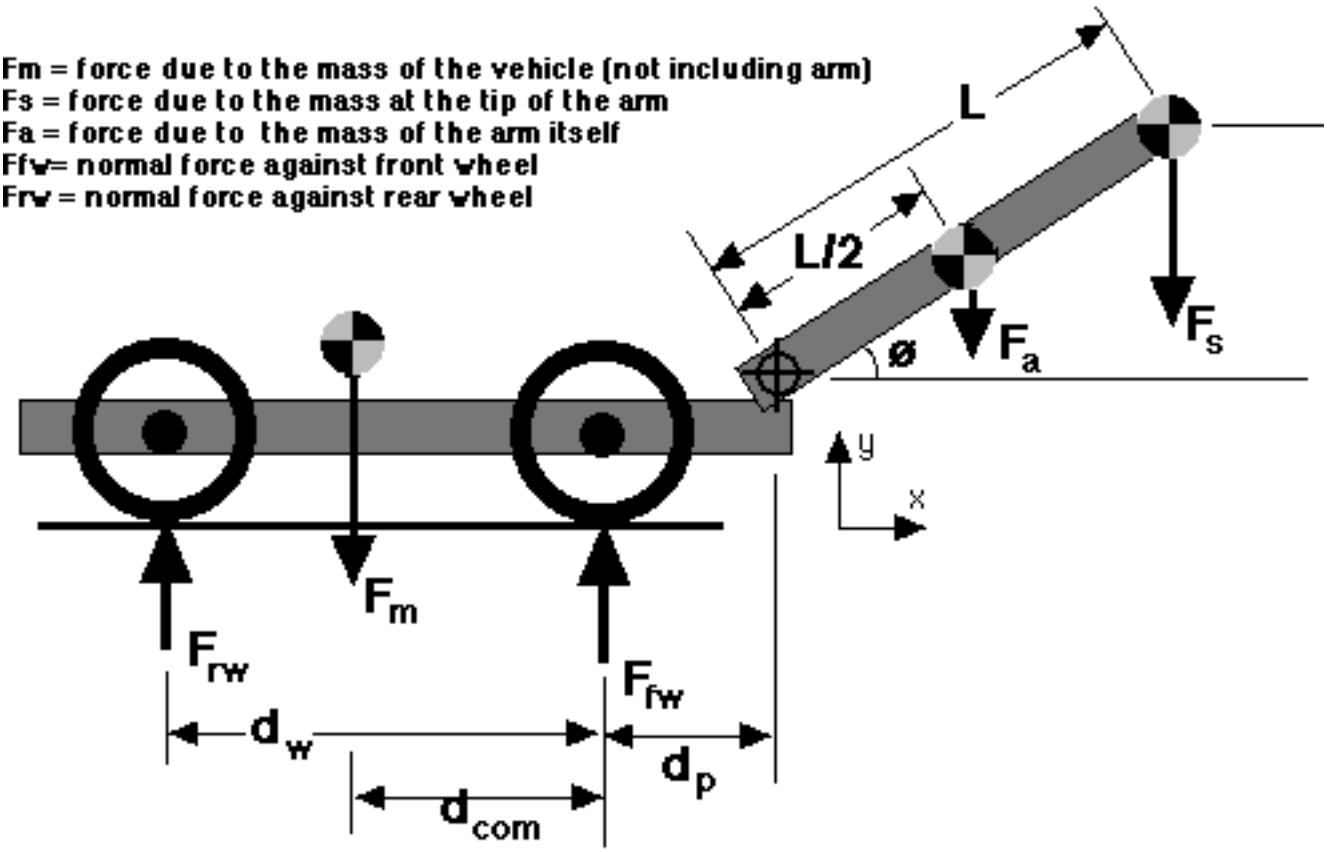
# Balance



## Balancing a Machine with an Arm

Fm = force due to the mass of the vehicle (not including arm)
Fs = force due to the mass at the tip of the arm
Fa = force due to the mass of the arm itself
Ffw= normal force against front wheel
Frw = normal force against rear wheel




dcom = distance from com to front wheel
dp = distance from pivot point to front wheel
dw = wheel base
L = length of arm

$$\sum F_y = 0: F_{rw} + F_{fw} - F_a - F_S - F_m = 0$$

$$\sum M_{fw} = 0: F_{rw} d_w - F_m d_{com} + F_a\left(\frac{L}{2}\cos\theta + d_p\right) + F_S\left(L\cos\theta + d_p\right) = 0$$

$$\rightarrow F_{rw} = \frac{F_m d_{com} - F_a\left(\frac{L}{2}\cos\theta + d_p\right) - F_S\left(L\cos\theta + d_p\right)}{d_w}$$

$$\rightarrow F_{fw} = \frac{F_m\left(d_w - d_{com}\right) + F_a\left(d_w + d_p + \frac{L}{2}\cos\theta\right) + F_S\left(d_w + d_p + L\cos\theta\right)}{d_w}$$

**Tipping of the machine occurs at the maximum load Fs =Fsmax when Frw = 0:**

$$F_{rw} = 0: \frac{F_m d_{com} - F_a\left(\frac{L}{2}\cos\theta + d_p\right) - F_{S,\max}\left(L\cos\theta + d_p\right)}{d_w} = 0$$

$$\rightarrow F_{S,\max} = \frac{F_m d_{com} - F_a\left(\frac{L}{2}\cos\theta + d_p\right)}{L\cos\theta + d_p}$$

**What can be done to maximize the load at which the machine starts to tip?**

- Increase the weight and hence the gravitational force of the machine
- Moving the center of gravity away from the front wheels
- shortening the length of the arm